Exhibit 4

EXPERT REPORT

In re Flint Water Cases
Civil Action No.5:16-cv-10444-JEL-EAS
(consolidated)

By:
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Submitted to:
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February 3, 2023

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1. INTRODUCTION

I was asked by lawyers for Veolia North America ("VNA") to perform a visual inspection of premise plumbing samples taken from two Flint, Michigan homes and made available at Christensen Materials Engineering, 89 Stephanie Lane, Alamo, CA on December 7, 2022, and to respond to opinions offered by Plaintiffs' expert, Dr. Larry Russell, based on those samples. The samples were removed from [redacted] and [redacted] in Flint in February 2022 by or at the direction of Dr. Russell. Neither I nor any representative of VNA were given notice of the sampling event, and did not participate in the sampling.

During the December 7, 2022 inspection, the samples were photographed by Nickolas Steinhoff of Applied Technical Service Phoenix. In addition, Mr. Steinhoff performed X-ray fluorescence (XRF) analysis of selected samples to confirm their material (1). The photos and XRF results are discussed in this report.

I was also asked to review the opinions of plaintiffs' expert, Dr. L. Russell, as presented in his Supplemental Report of October 18, 2022, which are discussed and rebutted where the sample inspection results contradict his opinions.

I reserve the right to supplement and amend my opinions based on and subject to review and analysis of additional discovery information I receive.

This report is respectfully submitted by,

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2. SUMMARY

1. Because there was no available documentation of the locations in the homes where the samples were removed, we could not confirm their exact location in the homes. Chain-of-custody from the homes to the possession of Dr. Russell was not provided, leaving uncertainty whether we have seen all of the piping removed. There was no documentation from the labs that performed measurements or the analysis, so we could not confirm whether they were certified or the equipment was properly maintained and calibrated. Such basic procedural deficiencies indicate a lack of familiarity with corrosion engineering and basic scientific procedure.
2. Storage of the samples was unacceptable, with no sealing of the ends of the tubes, and some evidence of storage in damp conditions which caused rusting and contamination of cut surfaces. In his deposition, Dr. Russell testified that he kept the box of pipe samples in his garage since February 2022, with some samples in individual bags and some not, which is not proper storage. Thus, contamination and degradation of the samples are very real concerns. Again, these deficiencies indicate a lack of familiarity with corrosion engineering and basic scientific procedure.
3. The problems with handling, principally resulting in the potential for contamination, mechanical damage, and scale degradation, mean that the results of analyses already performed by Dr. Russell are questionable.

<u>Copper Pipes</u>

4. The copper pipes samples from the homes were typical of residential copper piping, with no visual evidence of mechanical damage or deformation, corrosion pitting, or loss of thickness.
5. The copper pipe specimens did not show any significant wall loss. Though limited by the poor quality of sample preparation by Dr. Russell, our caliper measurements found the copper pipes were actually thicker than he claimed. There were no indications of the exact sites where Dr. Russell measured pipe wall thickness, again pointing to a failure to follow basic scientific procedures. In any case, most of Russell's measurements are within the range of tolerance per the specification for new copper piping and therefore do not support any claim of wall loss.
6. Surprisingly, no metallurgical cross-sectioning was done to confirm pipe wall thickness. Dr. Russell claims that the pipes were damaged, which was not evident, but cross-sectioning is basic procedure in any corrosion engineering failure analysis. There was ample pipe sample length to conduct cross-sectioning, but no explanation has been offered why cross-sectioning was not done.

7. Samples of the internal pipe surface were not cleaned to remove scale for visual or microscopic examination. There is no visual evidence of the inside surface of the piping, and only a thin oxide is visible. Thus, there is no evidence to support claims of corrosion damage. Some corrosion product from residual flux at joints is visible, apparently undisturbed since installation.

8. Dr. Russell's scraping of the inside surface to remove loose scale was done haphazardly and in a superficial manner that did not sample the full thickness of the oxide. It is likely that the sampled copper pipe wall scale is not representative, especially where the composition varies through the thickness of the scale.

Galvanized Steel Pipes

9. The condition of the galvanized pipe samples was typical of residential galvanized piping after many years of service. Some corrosion at screwed joints, weep spots where pits have penetrated through the wall, and significant internal scaling are what we would expect anywhere, especially after decades of use. The galvanized pipe samples are evidence of long life at Flint, and are in very good condition considering their age, estimated at 84 years at the [redacted] home. The galvanized pipe long ago exceeded its expected service life of 40-60 years (7).

10. Samples contained heavy scale, typical of decades-long exposure and not consistent with the scale removal and damage claimed by the plaintiffs to have happened during the use of Flint River water from April 2014 to October 2015.

11. There is no visual evidence to support Dr. Russell's claim of wall thinning – only isolated localized pin-hole pits which resulted in 'weepers.' These are typical of galvanized steel pipe after several decades of service, and there is no way to tell when the 'weepers' formed. Failure at threaded joints during disassembly was due to the thinned wall at the roots of threads cut in the pipe, and corrosion on the exterior where the protective galvanizing had been removed during thread cutting.

12. There was no indication that the samples had been sectioned to do metallurgical cross-sections. This is good practice for failure analysis of pipes and tubes to measure thickness. The thickness of cut samples appeared to be very good, with no evidence of significant attack. Certainly, the samples did not show "paper thin" or otherwise severely compromised walls. Evidence of compromise would have been visible macroscopically at pipe wall cuts, and it was plainly not present in the samples presented.

13. Sample areas of internal surface had not been cleaned to allow proper examination of whether damage has occurred. There was no cross-sectioning at pinhole pits to characterize the extent of attack or its causes.
14. Lead in the scale measured by Dr. Russell likely is from the original galvanizing layer. The weight percentage amounts of lead measured by ICAPS were about 1/100th of the weight percentage of lead that would have been present in the original galvanizing layer, so would be expected to be present.
15. There was no scale cross-sectioning for analysis of layers by Dr. Russell, which could have aided in determining the age of the scale. There was no indication where the scale sample was taken for analysis, and it may not be representative.
16. Analysis of the scale in tubercles on steel pipe is essential to determine the cause of that corrosion. Copper deposition from upstream copper piping or fittings onto the surface of steel piping can initiate localized corrosion by a galvanic action (5), which leads to the formation of tubercles, but the presence of copper in the tubercles was not investigated. Such copper deposition occurs independent of water quality and would be expected in any plumbing system with copper upstream of galvanized pipe.
17. There is no indication of when during the life of the pipes corrosion occurred. The quantity of scale points to the likelihood that it was undisturbed during the period of 2014-15. Based on my inspection, there is no reason to conclude that there was acceleration of corrosion during 2014-15.

3. QUALIFICATIONS

I, David Crowe, was retained by Campbell, Conroy and O'Neil, P.C. and Mayer Brown, P.C. in 2019 to provide expert witness services in the area of metallurgy and materials engineering. My assignment has involved review of claims of corrosion to domestic piping systems in Flint MI during the Flint Water Crisis in 2014-2015. I performed visual inspection of piping at two residences, and later inspected samples taken by Dr. Russell from both homes at a location in Alamo, CA.

I earned Ph.D. and Master's degrees in Metallurgical Engineering and a Bachelor's degree in Mechanical Engineering. I have taught graduate students and conducted industrial research at the Institute of Paper Chemistry, and have worked for a number of industrial corporations as a corrosion and materials expert, and am now a consultant. I have over 35 years of experience focused on metal equipment, covering failure analysis, materials selection and specification, corrosion research, welding and fabrication, and inspection of a broad range of equipment, including piping, pressure vessels, boilers, and tanks. I have worked on corrosion and materials

engineering in a number of industries including municipal water treatment, waste water treatment, pulp and paper, chemical manufacture, power generation, oil refinery and distribution, marine, transportation, and structures. This has encompassed many processes, mostly aqueous, and a wide range of materials. The performance of metals has been a focus of my work. Non-metals have been another major area of activity. My current curriculum vitae is attached in **Appendix A**.

I have not been deposed or offered testimony at trial during the last four years (2019-2022).

4. BACKGROUND

In fall 2020, I inspected the water supply plumbing for [redacted] and [redacted] *in situ* (2,3). On behalf of the plaintiffs, Dr. Russell unilaterally removed samples from the homes in February 2022. This was done with no notice to me, VNA, or its representatives, and with no participation by me or VNA. Dr. Russell's supplemental report, published in October 2022, summarized visual evidence on some samples after cross-sectioning, plus elemental analysis of samples (4).

When I inspected the plumbing at the two residences in the fall of 2020, I understood that we were limited to visual inspection and non-destructive testing. We also did not attempt to take samples from the homes because there was no external evidence of unusual corrosion at either location, and no information was provided indicating that any of the pipes had failed during or since 2014-2015. Furthermore, the piping has been in service several years since 2014-2015, and the condition inside the piping would have changed over several years of service. Any damage that occurred during 2014-2015 could not be distinguished from damage prior to or after 2014-2015.

In December 2022, we were permitted to visually examine the samples taken by Dr. Russell. Inspection was performed outdoors under variable lighting conditions, in front of a converted barn/garage at a residence at the back of the lot designated 89 Stephanie Lane, Alamo, CA, the location of Christensen Materials Engineering. There was no laboratory signage visible, and no certifications or accreditations posted in view.

Samples were placed on top of folding tables, **Figures 1 and 2**. Plaintiffs' counsel represented that no video was being taken. We were photographed by Mr. Todd Russell during our inspection, and there was an outdoor security camera, although it is unknown whether it was operational.

Facilities or equipment used for cutting or preparing the samples were not seen, with the exception of some stationary electric saws in the barn, and no analytical tools or instruments were shown.

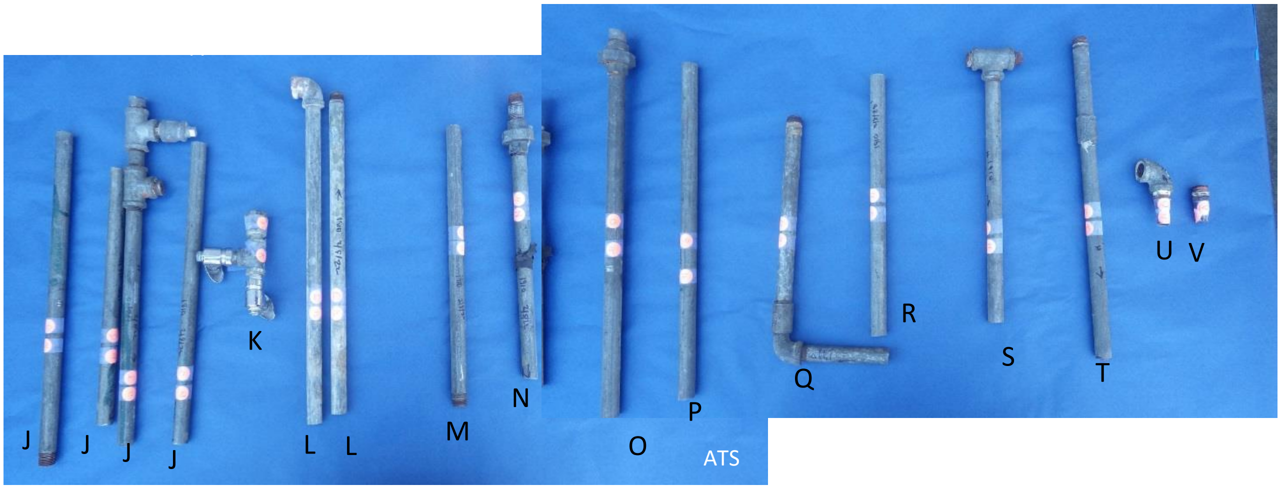

Figure 1. Samples of pipe laid out on the larger table.

Figure 2. Samples on the smaller table.

Provenance and Chain-of-Custody

The locations where samples were removed by Dr. Russell should have been photographed before removal. Locations of the specimens were not provided on the sample labels. Defendants were not informed of the removal of samples or given a chance to witness any work to section and examine the samples.

A list of samples, provided the day of the inspection, was consistent with the samples displayed. There is no way to confirm whether this list matches the samples taken from [redacted] and [redacted] homes. No chain-of-custody was provided except for the turnover of samples on 12/6/2022 from Larry Russell to Todd Russell, his son. A chain-of-custody document should trace where the samples have been in addition to who had control. The documentation should have recorded the repackaging a number of times and shown when and where they were stored. When the shipping container was broken by the airline, it should have been noted as it affected the integrity of subsequent analyses (9, second day, p.10, line 7).

Sample X, a sample of copper pipe, was displayed, but was not in the chain-of-custody document. There was no sample W (between V and X). Dr. Russell claimed in his deposition that no sample W was taken or marked. Because neither I nor anybody from VNA was present when Dr. Russell took the pipe samples, I have no way to verify Dr. Russell's assertion.

Storage

None of the samples had been sealed on the ends to prevent contamination. This left them open to contamination from material knocked off of the exterior of the pipe samples and from the general environment. The samples were placed together in a plastic storage container for shipment (9). Some of the samples were in plastic bags, some not. Samples could have been contaminated inside by material from the external surface of each sample which could enter the open ends of the pipe sections. Contamination could have occurred because the exterior of galvanized steel piping contains lead as a constituent. In addition, degradation due to exposure to the atmosphere may have taken place. For example, the wet pipe samples were sealed in bags and left in storage for months pending a decision to analyze them, allowing degradation of the scale, and possible corrosion of the pipe surfaces.

Rusting of cut surfaces suggested that the samples had been wet after cutting, perhaps due to poor storage. Thus the condition of the scale at this inspection could have been significantly different than it had been when the sample was removed. At the inspection, the samples were very dry, and the scale was friable, so the scale was easily damaged. Pieces of scale had fallen off of the pipe samples onto the table. These observations point out handling that is below minimum accepted standard practice.

5. OBSERVATIONS & DISCUSSION

5.1 Samples from [redacted]

Sample A – Copper pipe, Hot water

This sample corresponds to Figure 26 in the house inspection report (2), which illustrates exterior corrosion from flux residue. It was described in Dr. Russell's report Fig.4.1-1 and 4.1-2. His EDS results for scale analysis showed no lead was present in the solder or at detectable levels in the oxide on the pipe internal surface. He measured thickness at 0.026-in.

In **Figures 3 and 4**, variations in the wall thickness were seen between the pipe and fitting, but there was no evidence of corrosion of the inside surface at thinner areas. The thin scale is typical of scale seen in copper water pipes. The pipe thickness and general appearance were typical of copper pipe that has been in service for a few years. The areas of greenish scale may be related to flux residue which was left on the pipe during soldering. The remaining corrosion product from flux supports the position that no significant damage has occurred, particularly during the water crisis period, otherwise that corrosion product from flux would have been removed.

Evidence of superficial scratches on the inside surface appeared to have been from removal of loose scale for analysis by Dr. Russell. This scratch did not appear to have removed a constant thickness, or all of the oxide in one area, and the area was uncontrolled, so deposit composition measured by Dr. Russell may not be representative.

Copper water tube is typically manufactured to meet ASTM Specification B88. Dr. Russell identified the copper tube as Type M under this specification. The ½-inch tube has a specified wall thickness of 0.028-inch with a tolerance of 0.003-inch, **Figure 5.** The tolerance means it can be 0.028-inch plus or minus 0.003-inch, that is, from 0.025 to 0.031-inch thick. The 0.026-inch wall thickness measured by Dr. Russell meets the B88 specification for new copper pipe. There is no evidence of thinning in service based on the thickness he measured. Indeed, Dr. Russell acknowledged in his deposition that new copper pipe is often manufactured at the lower end of the specification range. Our measurements with calipers showed thicknesses over 0.032-in, that is, higher than Dr. Russell's values, and above the nominal range of thickness for new Type M copper pipe. Our measurement would have included oxide on the surface.

For comparison, I obtained a section of new Type M ½-inch copper tube from Home Depot on January 26, 2023 and measured the wall thickness of the copper tube with calipers, as illustrated in **Figure 6**. The thickness at four points 90° apart around the circumference was 0.026, 0.027, 0.026 and 0.027 inches. These measurements met the specification for new Type M copper tube ½-inch diameter which is 0.028±0.003 inch. These comparison measurements show that the copper tube in the [redacted] home was 'as-good-as-new' in terms of thickness.

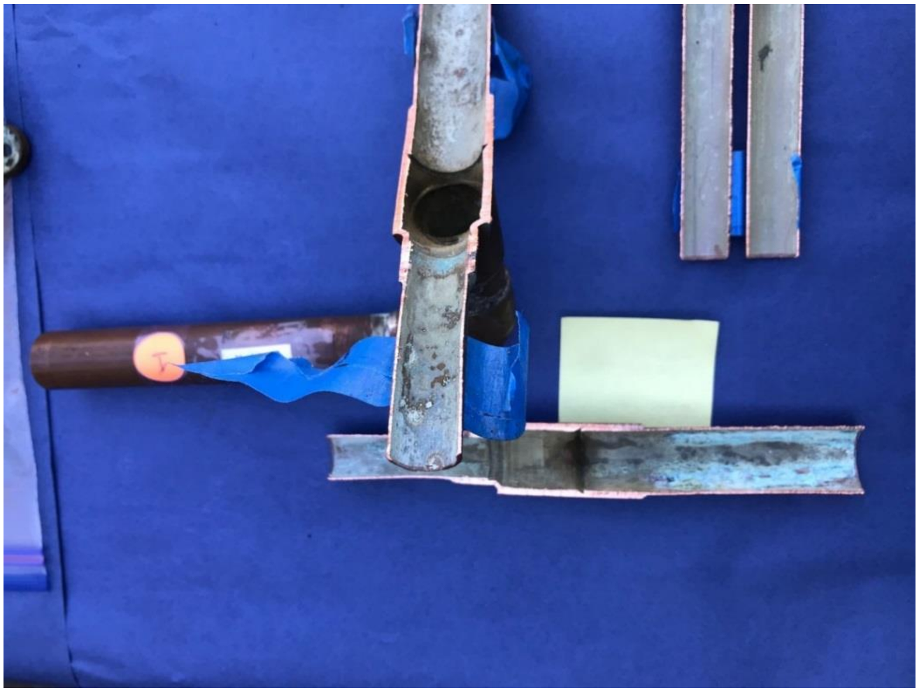

Figure 3. Sample A, copper hot water pipe, with greenish corrosion product.

Figure 4. Sample A – Copper hot water line, with green corrosion product likely from flux residue.

B 88 – 03

TABLE 1 Dimensions, Weights, and Tolerances in Diameter and Wall Thickness for Nominal or Standard Copper Water Tube Sizes
(All tolerances are plus and minus except as otherwise indicated)

Nominal or Standard Size, in.	Outside Diameter, in.	Average Outside Diameter[A] Tolerance, in.		Wall Thickness and Tolerances, in.						Theoretical Weight, lb/ft		
				Type K		Type L		Type M				
		Annealed	Drawn	Wall Thickness	Toler-ance[B]	Wall Thickness	Toler-ance[B]	Wall Thickness	Toler-ance[B]	Type K	Type L	Type M
¼	0.375	0.002	0.001	0.035	0.0035	0.030	0.003	[C]	[C]	0.145	0.126	[C]
⅜	0.500	0.0025	0.001	0.049	0.005	0.035	0.004	0.025	0.002	0.269	0.198	0.145
½	0.625	0.0025	0.001	0.049	0.005	0.040	0.004	0.028	0.003	0.344	0.285	0.204
⅝	0.750	0.0025	0.001	0.049	0.005	0.042	0.004	[C]	[C]	0.418	0.362	[C]
¾	0.875	0.003	0.001	0.065	0.006	0.045	0.004	0.032	0.003	0.641	0.455	0.328
1	1.125	0.0035	0.0015	0.065	0.006	0.050	0.005	0.035	0.004	0.839	0.655	0.465
1¼	1.375	0.004	0.0015	0.065	0.006	0.055	0.006	0.042	0.004	1.04	0.884	0.682
1½	1.625	0.0045	0.002	0.072	0.007	0.060	0.006	0.049	0.005	1.36	1.14	0.940
2	2.125	0.005	0.002	0.083	0.008	0.070	0.007	0.058	0.006	2.06	1.75	1.46
2½	2.625	0.005	0.002	0.095	0.010	0.080	0.008	0.065	0.006	2.93	2.48	2.03
3	3.125	0.005	0.002	0.109	0.011	0.090	0.009	0.072	0.007	4.00	3.33	2.68
3½	3.625	0.005	0.002	0.120	0.012	0.100	0.010	0.083	0.008	5.12	4.29	3.58
4	4.125	0.005	0.002	0.134	0.013	0.110	0.011	0.095	0.010	6.51	5.38	4.66
5	5.125	0.005	0.002	0.160	0.016	0.125	0.012	0.109	0.011	9.67	7.61	6.66
6	6.125	0.005	0.002	0.192	0.019	0.140	0.014	0.122	0.012	13.9	10.2	8.92
8	8.125	0.006	+0.002 −0.004	0.271	0.027	0.200	0.020	0.170	0.017	25.9	19.3	16.5
10	10.125	0.008	+0.002 −0.006	0.338	0.034	0.250	0.025	0.212	0.021	40.3	30.1	25.6
12	12.125	0.008	+0.002 −0.006	0.405	0.040	0.280	0.028	0.254	0.025	57.8	40.4	36.7

[A] The average outside diameter of a tube is the average of the maximum and minimum outside diameter, as determined at any one cross section of the tube.
[B] Maximum deviation at any one point.
[C] Indicates that the material is not generally available or that no tolerance has been established.

Figure 5. Tube dimensions from ASTM B88 (2).

Figure 6. The wall thickness of a piece of new Type M 1/2-inch copper pipe was measured at 0.026, 0.027, 0.026 and 0.027 at four points 90° apart around the circumference. The measurement of 0.026 meets the nominal thickness for the pipe, which is 0.028±0.003 inches.

Sample B – Copper pipe, Cold water

Sample B, illustrated in **Figures 7 and 8**, is from a cold water line at [redacted] Sample B is shown in Russell Fig. 4.1-3 and 4.1-4 (4). The location where this sample was removed is unknown.

The internal surface was in excellent condition, with no damage. It was covered with a thin layer of oxide, typical for copper pipe. It had been scraped off in one location. There was no evidence of pitting or localized corrosion. The outside surface had greenish corrosion products from flux residue.

The oxide on the inside of the copper pipe was very thin, on the order of nanometers, so it would have been impractical to obtain a sufficient sample for ICAPS analysis of lead. However, considering the thinness of the oxide, no significant reservoir of lead would be expected to be present. The thin oxide also could not conceal damage – and none was seen.

I measured the thickness at the end cut using calipers, but a burr on the edge of the sample precluded an accurate measurement.

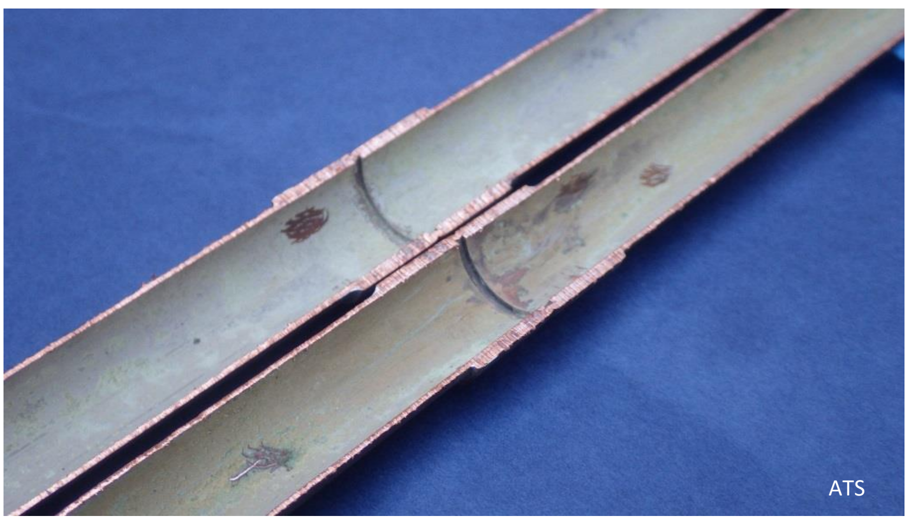

Figure 7. Sample B, Copper cold water line from [redacted]

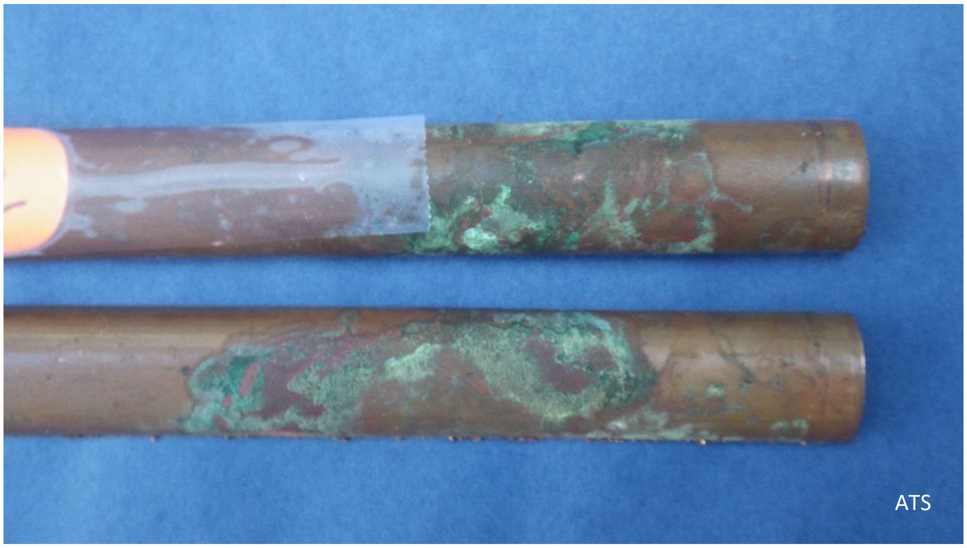

Figure 8. Sample B, copper cold water pipe with corrosion product from flux on the outside surface. This corrosion product is external only, and does not correspond to any area of attack inside.

Sample C – Galvanized pipe and valve from upstairs bathroom (cold water).

The location of removal of Sample C can be seen in Fig. 7 of the home inspection report (2), but Dr. Russell did not cut out this sample, and it was found in the basement by him. Sample C, **Figures 9 and 10**, shows no evidence of significant wall loss, but the cut surface, where the sample was sawn longitudinally, has rusted after cutting. The internal scale was less voluminous that in some other pipe samples. Variations in color are typical of scales in steel pipes, and may result from differences in oxidation state of the rust, or may result if top layers are knocked off during handling. Dr. Russell's report did not discuss galvanized pipe at [redacted], and did not claim damage of the galvanized line there. He did perform scale analysis via ICAPS and found 114 mg/kg lead. Expressed at weight percent of the deposit, it is 0.0114%. This lead is likely residual from the lead that was present in the original zinc galvanizing layer.

Some explanation regarding the composition of galvanizing helps in understanding the presence of lead in the scale. Galvanizing is specified by ASTM Specification B6 (8). It specifies the composition of zinc used in the galvanizing, in which steel pipes are dipped in a molten bath of zinc to coat them. "Prime Western" zinc was typically used for galvanizing pipe, and it has maximum limits of 1.4% lead, 0.20% cadmium, 0.05% iron, and 0.02% copper. It will not be surprising to find 0.0114% lead in the scale when the original galvanizing layer contained 1.4% lead, about 1/100th of the content of lead in the original coating. Finally, lead from the galvanizing layer on the exterior surface could have been carried to the inside of the pipe by the saw teeth as the blade passed through the pipe, contaminating the interior with lead. Indeed, at

the levels detected, this is possibly the source. The galvanizing layer should have been removed from the exterior of the pipe where the pipe was to be cut by the saw. Due to this error in cutting, measurement of small concentrations of metallic elements are questionable.

In **Figure 10**, note the ends of the sample sections, which are threaded. During fabrication of the piping joints, threads are cut in the ends. This cutting breaks and removes the galvanized coating layer, exposing the steel to the atmosphere, which corrodes from the exterior. Also note that the threads are cut deeper as they approach the end of the pipe, resulting in thin wall at the root of the thread. When disassembling old pipe, it is often this thinned area at the root that tears before the rusted joint is loosened. Steel-to-steel joints rust tightly due to oxide corrosion product forming between the teeth, and due to its higher volume compared to the steel it came from, forming a joint with compressive stresses which must be overcome during opening. Good pipe sampling technique would call for samples to be cut out where possible, not disassembled with wrenches, which could cause mechanical damage to the samples. There is no apparent reason why Dr. Russell could not have used a pipe cutter instead of wrenching the samples loose, causing damage.

Figure 9. Sample C, galvanized steel pipe and valve apparently from the cold water line to the upstairs bathroom sink. The valve is heavily scaled inside with deposits similar to the inside of the pipe, and did not appear to be typical of corrosion products from dezincification.

Figure 10. End view of Sample C. Note the full wall thickness and rust on the cut surfaces.

Sample D – Galvanized pipe and valve from upstairs bathroom sink (hot water).

The location of removal of sample D is illustrated in Fig. 7 of the home inspection report (2), but Dr. Russell did not cut out this sample, and it was found in the basement by him. The pipe wall of Sample D, **Figure 11**, showed rusting of the cut surface, but this was superficial flash rusting of a fresh surface exposed to moisture. This observation points to the likelihood that the samples were poorly stored and, at some point, were wet during storage. **The wall had not lost thickness, despite the cross-section appearance that it had corroded**. Heavier scale in Sample D compared to Sample C may be because Sample D was from the hot water side, and more corrosion would be expected in hot water. Dr. Russell's ICAPS analysis (4) found 145 mg/kg lead in the scale, that is, 0.0145% by weight. This is likely residual lead from the original zinc galvanizing layer. EDS showed that the scale was mostly iron oxide. There was significant corrosion at the junction of the pipe with a fitting, **Figures 12 and 13**. This is typical of old galvanized piping systems. XRF analysis by ATS (1) showed that this fitting with bracket contains copper, lead, and zinc, consistent with brass. The end of the pipe in the foreground of **Figure 12** shows external corrosion and tearing failure at the threads during disassembly as already discussed.

Figure 11. Sample D, galvanized steel hot water pipe apparently from the upstairs bathroom sink, with shut-off valve.

Figure 12. Sample D, galvanized steel hot water pipe from upstairs bathroom illustrating corrosion at the brass fitting, where damage to the galvanized coating by threading had permitted corrosion.

Figure 13. Sample D, fitting with corroded galvanized steel hot water pipe in the end, from the upstairs bathroom at [redacted]

5.2 Samples from [redacted]

Sample E – Hot water copper pipe at water heater

Sample E is shown in **Figure 14**. Its location was illustrated in Fig.4 of the home inspection report (3). Note the thin, uniform oxide on the internal surface. It was Fig. 4.2-1 and 4.2-2 in the Russell report (4). Dr. Russell reportedly measured a thickness of 0.019-in. but gave no indication of where he had measured. Visually, the outside of the bend was thinner due to stretching when the bend was formed. It should be noted that the elbow does not appear to be made to a specification. The sharp inside (intrados) bend has a crimped appearance which is not acceptable and the extrados is flattened and thinned in appearance. This elbow appears to be homemade. **Figure 15**, further below, shows a similar elbow, and it does not meet specifications (or sample elbows available for purchase). Note the thick wall on the intrados and the thicker wall on the extrados where the tube has been stretched around the bend. Because these elbows are not spec grade, there is no information on their original thickness when new.

There was also thin tube adjacent to the fitting, and that may have been abraded during fit-up to fit it into the fitting; this is not evidence of corrosion. Internal surface examination would be required to determine whether corrosion may have occurred, but the scale uniformity suggests that no corrosion ever occurred. There is no visual evidence of attack or damage on this sample.

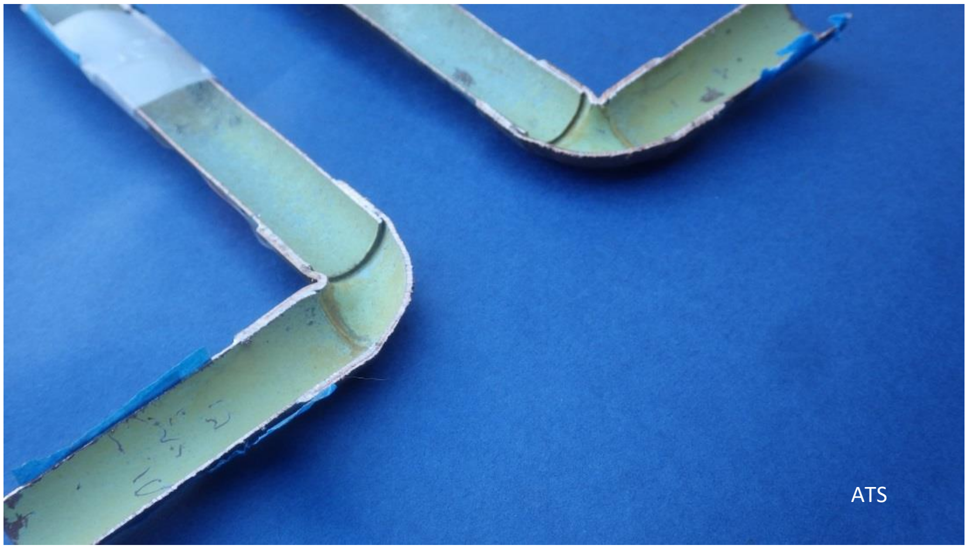

Figure 14. Sample E, hot water pipe at the water heater.

Sample F - Cold water copper pipe at water heater

The location of Sample F is believed to be shown in Fig. 4 of the home inspection report (3). Sample F, illustrated in **Figure 15**, corresponds to Fig. 4.2-3 and 4.2-4 in Dr. Russell's report (4). No attack or damage is seen on this sample. Dr. Russell measured 0.026-in. thickness but our measurements with calipers showed it to be 0.034-in. and higher. We do not know where Dr. Russell measured, and it may have been on the extrados of the elbow bend, or at the joint which was abraded to fit into the bend. As already discussed for Sample A, the tolerance specification of the Type M piping allows a thickness of 0.025-inch, so there is no evidence here of any loss of thickness. Visually, we do not see any evidence of damage.

Caliper measurements could not be performed in some places to confirm thickness due to a cutting burr on the end edge of the sample. Where the burr was missing, all measurements made were well over the thickness claimed by Russell in his Opinion 5-5.

Russell reported analysis showing there was no lead in the solder joints. He detected lead in the scale of a brass coupling, and that lead would be part of the brass alloy, not a contaminant.

Figure 15. Sample F, copper cold water pipe at the water heater.

Sample G – Galvanized pipe with through-wall pit in the tee

Figure 16 illustrates Sample G, a tee with a pin-hole leak. The location of this sample may be shown in Fig.7 of the home inspection report (3). It is also shown in Figures 4.2-6 and 4.2-7 in Dr. Russell's report (4). There was heavy internal scale, but no evidence of significant wall loss, especially not areas that were 'paper thin' as claimed by Dr. Russell in his supplemental report Opinion 5-6 (4). Rusting of the cut surface, as indicated by yellow arrows in **Fig. 16**, points to poor storage of the samples. ICAPS (4) found 41.8 mg/kg lead in the scale (0.00418% by weight). Dr. Russell's EDS analysis found significant zinc, so some of the original zinc galvanizing layer may be present here, and would be expected to contain some lead as discussed under Sample C.

Corrosion of the fittings resulted in a weep spot where a pit has perforated the wall, and water has seeped out through corrosion deposits sealing the hole. These are typical of old galvanized piping. There is no way to tell when the weep spot formed (e.g. before, during or after 2014-2015). The age of the piping here is unknown, but if it dates from the construction of the house in 1938, then it has provided service well beyond its expected life. Usually a life of 40 to 60 years would be regarded as very good for galvanized piping (7), and this appears to have lasted 84 years.

Further cross-sectioning of the sample at the weep location would have aided in determining the cause. Upstream copper piping sheds copper, which can deposit onto the waterside of steel piping downstream. The copper acts as a cathode with the iron an anode, resulting in corrosion of the iron. This localized attack can lead to the formation of a tubercle. Dr. Russell overlooked this possibility, or any other, through his superficial failure analysis.

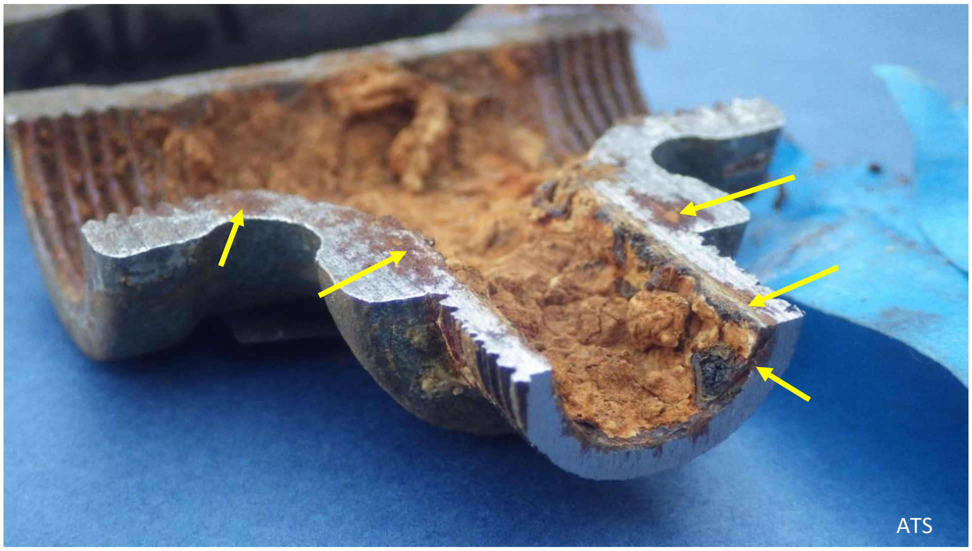

Figure 16. Sample G, internal surface of the tee in a galvanized line. A pinhole corrosion site is located underneath the scale. Rusting of the cut surface is indicated by the yellow arrows. This rusting is not indicative of through-wall pitting and does not compromise the integrity.

Sample H – Galvanized pipe

Sample H is shown in **Figures 17 and 18**. The location of the sample can be seen in Fig. 6 of the [redacted] house inspection report (3). The sample was illustrated in Figures 4.2-8 and 4.2-9 of Dr. Russell's report (4).

Heavy internal scale is seen when cross-sectioned. A weep mark on the exterior has resulted from an oxide-filled, through-wall pit. Weeps can be present for many years without progressing to an active leak. There were no active leaks observed during inspection of this home in 2020 (3). There is no general wall loss, and the dark stains on the cut surface are from rusting of the cut edge of the pipe. EDS of the scale by Dr. Russell (4) found significant amounts of zinc from galvanizing. Lead was below detection levels by EDS, but ICAPS found 168 mg/kg. This lead is likely from the original zinc galvanizing, as discussed for previous samples above.

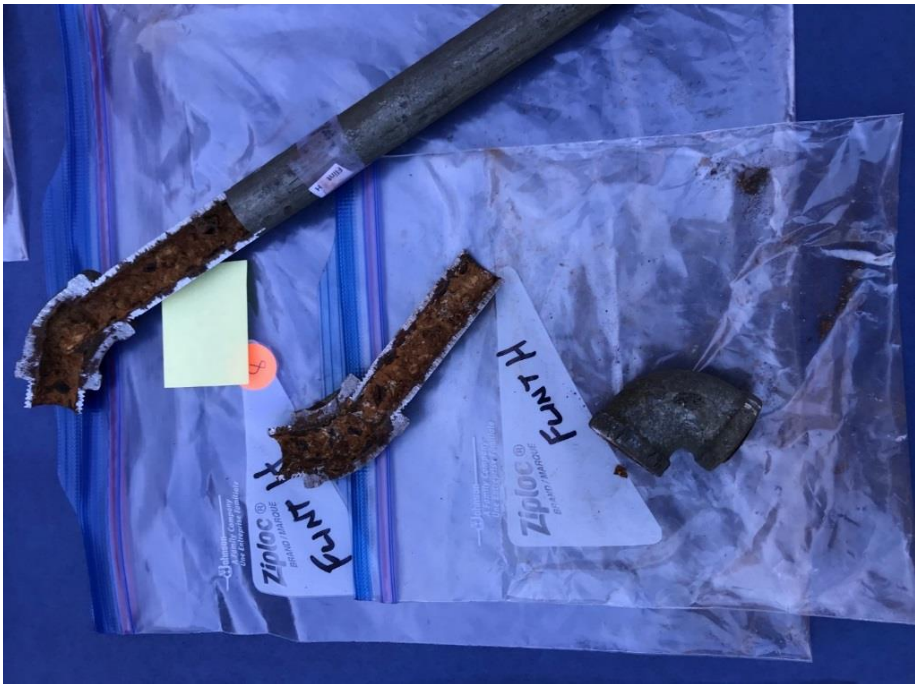

Figure 17. Sample H, galvanized line with a through-wall pit.

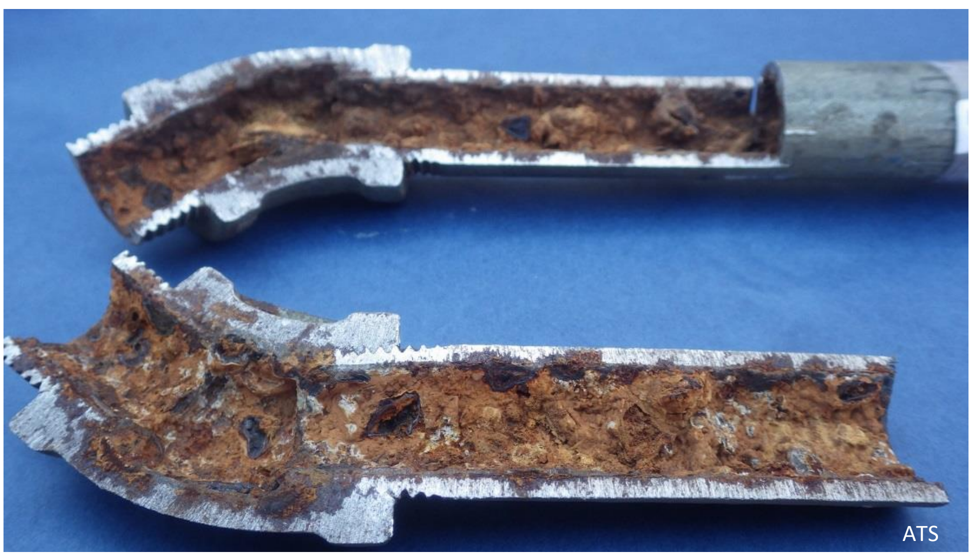

Figure 18. Sample H, close-up. The dark areas are where the red-brown scale has spalled off, revealing underlying black scale. This appearance of a red-brown surface rust, with darker form of rust underneath is typical in well-established corrosion of iron in water. There is no indication this was new scale. The discoloration on the cut surface is rust from poor storage, not corrosion or thinning into the pipe wall itself.

Sample I - Galvanized pipe

Sample I is shown in **Figure 19**. In Dr. Russell's report (4), this was in Figures 4.2-10 and 4.2-11. Thick scale was observed. The wall thickness appears to be uniform, suggesting that slow, uniform corrosion has occurred over the life of the pipe. Again, the discoloration on the cut surface is rust from poor storage, not corrosion or thinning into the pipe wall itself. EDS found zinc in the scale from galvanizing, and ICAPS found 83.3 mg/kg lead, again expected as a residual constituent of the galvanizing layer.

Figure 19. Sample I with thick scale at a bend. Note the rust on the cut surface from poor storage.

Sample J - Galvanized pipe

This sample was 4 pieces: ½ inch – 18.25, 14.125, 19 (tees), 16.5 inch, reportedly from a hot water line. The sections of pipe had traces of green paint on the exterior. Inside, heavy scale was observed, seen in **Figure 20**. In the Figure, note the thick wall of the pipe.

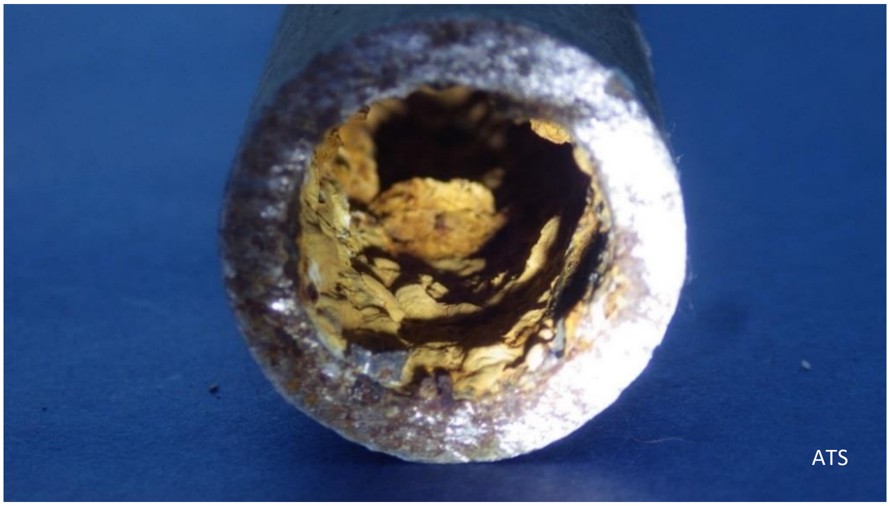

Figure 20. Sample J, galvanized pipe with thick scale seen from the end. Again, the cut surface was rusted.

Sample K - Galvanized pipe/valves Hot 6 by 4 inch two angle stops

Further visual examination was not performed. XRF confirmed it is galvanized steel, with a brass shut-off valve.

Sample L, - Galvanized pipe

Sample I was in two pieces, as seen in **Figure 21**. Both pieces have heavy internal scale **Figure 22**, preventing direct sight of light through the pipe. There was a weep spot from a through-wall pit on the 90-degree elbow.

Figure 21. Sample L galvanized steel pipe in two sections.

Figure 22. End view of Sample L, illustrating heavy internal scale but no compromise of the robust pipe wall.

Further examination of Samples M through S was not performed, and they are only listed below.

Sample M – Galvanized pipe ½ inch 15.5 inches, Heavy scale

Sample N - Galvanized pipe ½ inch 14.5 inch with union, Heavy scale

Sample O – Galvanized pipe ½ inch 20.5 inches, Heavy scale

Sample P - Galvanized pipe ½ inch 18 inches, Heavy scale

Sample Q - Galvanized pipe ½ inch 90 el 19 inches, Heavy scale

Sample R - Galvanized pipe ½ inch 14 inches, Heavy scale

Sample S - Galvanized pipe ½ inch 14.75 inches with tee, Heavy scale

Sample T - Galvanized pipe ½ inch 17.25 inches with coupling

Sample T, shown in **Figure 23**, was obstructed with internal scale.

Figure 23. Sample T, in the red box, had heavy rust deposits inside.

Sample U – Copper and galvanized

Sample U, reportedly a hot water line was ½ inch 90° elbow, 2 inch copper

Sample V – Copper

The wall thickness was measured at the end, with calipers at 0.036-inch. This is higher than the copper tube thicknesses measured by Dr. Russell.

Sample X – Copper

Sample X was not identified in the chain-of-custody document, but writing on the side identifies it as from a hot water line. It had clean solder work, with very little excess solder, and no residual flux seen.

5.3 XRF Results

X-Ray Fluorescence analysis (XRF) is for materials identification. Elemental composition is semi-quantitative only, meaning that concentrations measured are approximate. In addition, the instrument analyzes only a thin layer of the surface, so can be affected by surface contamination or differences resulting from manufacture or subsequent handling. The surfaces were not cleaned or prepared prior to making the measurements.

The lead detected in the pipe wall is expected, and likely results from the original galvanizing layer. For galvanized steel pipe, we see significant lead in the zinc galvanizing layer. Lead is included in the galvanizing bath to improve fluidity.

6. DISCUSSION OF OPINIONS IN SUPPLEMENTAL REPORT OF DR. RUSSELL, 10-18-22

6.1 Opinion S-2

> Dr. Russell Opinion S-2: "*As demonstrated in this report, essentially all of the homes in Flint (37,000) were built before 1985 when high lead solder was still in use and the homes with copper pipes have substantial amounts of leaded solder and are connected to high lead valves and faucets throughout Flint. Over 60 percent of Flint homes were built before 1945 when lead service laterals were still in common use.*" (4)

Dr. Russell claimed that high lead solder is present in copper piping, but found none in either of the homes from which he sampled copper piping. Nor did he show any damage to lead-containing valves or faucets.

Dr. Russell notes in Section 3 of his supplemental report that the majority of homes in Flint were built prior to 1960 before copper pipes were widely used. He provides no information on when galvanized piping, installed widely before 1960, was replaced. For piping installed after 1935, for example, replacements would likely have been made from the mid-1980's onward (based on the expected lifespan of galvanized steel pipe). Lead-free solder was used after 1986, so most replacement copper piping would have lead-free solder, and this was found in both of the homes where samples were taken.

Furthermore, Dr. Russell claims that 60% of homes were built before 1945 and would have had lead service lines, but his Table 3.4 indicates that a survey in 2017 found only 7.32% of service lines were lead.

6.2 Opinion S-3

Dr. Russell Opinion S-3 *"By focusing on two homes of named plaintiffs, namely* [redacted] *and* [redacted]*, the defendants artificially narrowed the useful data collected during their field work. To be consistent with the defense focus, I chose to remove pipe sections from those same houses to avoid adding even more variables into the data being collected. Reviewing the pipes from two homes provides infinitely more information/ data than was collected during the defense review of these homes, as the interior of the pipes can be observed and analytical measured."* (4)

In the fall of 2020 I inspected the plumbing at [redacted] and [redacted] because these were two of the three homes offered for inspection by the plaintiffs. I was unable to inspect the third home offered because I developed Covid-19 or flu symptoms the day after inspecting the first two homes. According to my understanding, the plaintiffs' legal team refused to reschedule. Thus, the plaintiffs' lawyers narrowed the access to homes, not the defendants.

Dr. Russell's inspection of the inside of the pipes several years after the water source was switched back to DWSD has limited value because after several years we cannot know what characteristics of the condition of the pipes date from before, during, or after 2014-2015. Scales and corrosion products will have reformed and deterioration likely occurred between 2016 and now, and this damage or change cannot be distinguished from older changes.

6.3 Opinion S-4

Dr. Russell Opinion S-4 *"The Detroit Water and Sewage Department's ortho phosphate addition corrosion treatment regime was (and is) very effective at minimizing corrosion of copper pipes in Flint. The effective corrosion rate of the DWSD water in the copper pipes observed was substantially less than the 0.0005 inches (0.5 mils) per year utilized by the Copper Development Association (CDA) in their 50 year warranty for copper pipe."* (4)

The Copper Development Association may have indicated an expected life for copper pipe of 50 years, but this does not imply that the corrosion rate would be 0.5 mpy. Dr. Russell seems to have arrived at this conclusion by dividing the thickness of a tube wall (0.028-inch) by 50 to obtain a loss rate of 0.5 mpy so that the wall thickness would be lost in 50 years. In fact it would fail before it thinned to nothing. Furthermore, the actual corrosion rate would be much lower. Our inspection of the tubes taken from the subject homes shows they have suffered no demonstrable loss. This includes the time of exposure to Flint River water, which evidently caused no damage. This suggests that orthophosphate has very little influence on corrosion of copper piping.

The thickness measurements made by Dr. Russell on the copper pipe samples could not be duplicated; we measured higher thicknesses. At any rate, the thicknesses measured in Table 5.1.1 were within the tolerance for manufacture of new tube, so there was no evidence of loss. Indeed, Dr. Russell acknowledged in his deposition that new copper pipe is often manufactured at the lower end of the specification range. I also found the same 0.026-inch thicknesses measured by Dr. Russell in new copper pipe from a hardware store. Visually, the inside surface looked smooth and covered with a thin oxide layer.

6.4 Opinion S-5

Dr. Russell Opinion S-5 *"The copper pipes at* [redacted] *were reportedly installed in 2008 during a plumbing remodel and as such they were assembled without leaded solder. These pipes were however impacted by the corrosive water served during the Flint Water Crisis losing approximately 0.002 inches of their wall thickness."* (4)

The assertion that the copper pipes at [redacted] lost 0.002-in. thickness is based on erroneous assumptions and errors in calculation of corrosion rates. That calculation requires an initial thickness and a final thickness. The loss is the difference in these two values. But Dr. Russell does not know the thickness at the beginning of 2014-2015, so he assumes it was the original wall thickness of new pipe; in doing this he ignores the loss in thickness of the wall between its installation and the beginning of 2014-2015, and any possibility of wall thickness below nominal due to normal manufacturing variations. He also does not know the thickness at the end of 2014-2015, so he uses the current thickness, ignoring loss of thickness that could have occurred between the end of 2014-2015 and now.

In any case, there is no visual evidence of corrosion to support the claim of thinning. Dr. Russell just assumes that damage occurred during 2014-2015, a belief that has no factual basis. And Dr. Russell's claim that the copper pies at [redacted] lost 0.002-in. thickness is entirely unfounded. Dr. Russell's wall thickness measurements are within the tolerance for new Type M copper pipe. The wall thickness measurements taken by Dr. Russell are entirely consistent with new copper pipe.

With no evidence of corrosion, the precise year in which the copper pipe was installed does not matter because any calculated corrosion rate is practically zero. However, in his deposition, Dr. Russell agreed that the homeowner indicated that the copper pipes were installed in [redacted] in 2000, not 2008 as Dr. Russell claimed in his report. Dr. Russell testified in his deposition that the installation of the copper pipes in 2000, not 2008, makes his opinions stronger. I disagree. To the extent the copper pipes experienced any loss of wall thickness (and there was no evidence of

that), the installation of the pipes in 2000 rather than 2008 means that they are eight years older than Dr. Russell assumed and provides an additional eight years when any loss of wall thickness could have occurred for reasons entirely unrelated to the water switch in 2024-15.

6.5 Opinion S-6

Dr. Russell Opinion S-6 *"The steel pipes at* [redacted] *were impacted severely during the exposure to the corrosive water during the Flint Water Crisis. These pipes experienced through wall pitting and were down to paper thin remaining wall thickness in many locations at the time that I removed them.* (4)

The steel pipes at [redacted] were decades old, and were, and are long past their expected life. Weeping at oxide-filled pits in galvanized line is expected, especially in piping estimated to be 84 years old. This is not evidence of a severe event, which would likely have opened up all the weepers. There is also no way to tell whether any through-wall pitting occurred before, during, or after 2014-15.

Due to exposure for several years after the Flint water event, the pipes tell us nothing about what may have occurred during the event. Looking at the samples, it is evident that the surfaces are well covered with iron oxide and mineral scale which protects the underlying steel from exposure to water. These corrosion products are typical in steel and cast iron lines, and they build up over time, eventually plugging the line in some service locations. There is no way to tell whether these oxides were disturbed during the Flint water event. Their thickness suggests that the scale has never been disturbed enough to wash it away. Visual inspection shows the pipe wall to be very thick in all of the cross-sections. Dr. Russell's claim that severe corrosion occurred during the Flint water event is entirely unsupported.

6.6 Opinion S-7

Dr. Russell Opinion S-7 *"Exposure to the corrosive water distributed during the Flint Water Crisis substantially compromised the life span of the steel pipes in Flint. Just as the steel pipe service laterals were removed by the City and replaced with copper, the steel pipes within these homes require replacement to halt exposure to the lead containing scale accumulated over many years from their lead service laterals. The Flint Water Crisis made these lead scales more readily exposed due to the aggressive Flint River water attack on these scales. Replacement is required to provide the residents with a plumbing life span required to service these homes in the future without catastrophic leakage and failure in the future."* (4)

Dr. Russell stated in his opinion that the "water distributed during the Flint Water Crisis substantially compromised the life span of the steel pipes in Flint" and that they could fail or leak catastrophically. The pipe samples from [redacted] are likely 84 years old, as discussed in the section "Sample G" in this report, so the expected life span has long ago passed, and still the pipe was in service with only a few weep spots until Dr. Russell removed the pipes in 2022. Considering the thick walls seen in the cross-sections, the pipe likely could have continued in service for many more years. I am also unaware of any reports of widespread failures of galvanized steel pipes in Flint during and after 2014-15.

Dr. Russell claims that the Flint water event exposed lead corrosion products in the scale, creating an on-going risk to residents. Visual examination of cross-sectioned tubes shows heavy scale inside the lines, contrary to any assertion that the Flint River water exposed lead-containing material. In addition, analysis of the scale by ICAPS reported by Dr. Russell in his supplemental report found 0.00418 weight percent of lead (41.8 ppm), a tiny fraction of the amount in the original zinc coating, which was likely 'Prime Western' zinc containing up to 1.4 weight percent lead as discussed in this report under "Sample C', p.14. This trace amount of lead could have been introduced due to uncapped pipe ends during shipping, or by the saw during sectioning.

As discussed above, the galvanized steel pipe samples taken from [redacted] are typical of residential galvanized piping after many years of service and do not show any sign of accelerated corrosion related to the water switch in 2014-15. Even if the pipe samples from [redacted] showed damage, however, it is speculative to extrapolate from pipe samples **in a single home** that all galvanized steel pipe throughout an entire city need replacement.

6.7 Opinion S-8

Dr. Russell Opinion S-8 *"Based on the work of Dr. Marc Edwards in 2015, the steel pipes in Flint were rapidly aged by the distributed Flint River water. The treated Flint River water was more than 8.5 times more corrosive than the DWSD water resulting in the pipes experiencing over 11 years of additional corrosion damage in the 16 months during the Flint Water Crisis. The resulting damage is a direct analogy to the 'straw that broke the camel's back' rendering the homes to require full pipe replacement."* (4)

Dr. Russell claims that the life of piping has been shortened significantly based on the testing result published by Dr. Marc Edwards for corrosion of nails in water from a home with uncommonly poor quality water. Dr. Edwards' nail study is not representative because the presence of scale and corrosion deposits on the surface of

galvanized steel pipes, as would be present in home plumbing, would have resulted in much lower corrosion rates.

The demonstration of corrosion of bare, abraded nails in Flint River water by Dr. Edwards in 2015 did not represent what would happen in real piping that has been in service for years. The principal difference is that oxide scale build-up over many years provides protection to the galvanized steel piping. The testing of corrosion protection strategies performed in the EPA test rig uses sections of line with typical scale intact on the inside surface, carefully mounted into a flow loop, with water flowing through it. This is how corrosion testing for water systems should be performed to obtain meaningful results.

Other differences between the nail test and real pipe are that the surface of the nails was cleaned, but real pipe would have been left with its oxide surface to provide protection. Nails are typically a poorer grade of steel with inclusions and other impurities which would serve as initiation sites for corrosion, and would tend to accelerate corrosion rates. Nails are also heavily cold worked, and this would increase the corrosion rate significantly, exaggerating differences in side-by-side comparisons.

If the exposure to Flint River water had been as severe as claimed by Dr. Russell, numerous failures of piping would have been reported, as piping nearing the end of its life was pushed over the limit. These reports would have increased in number as the water event continued. To my knowledge, there were no reports in the press or otherwise that indicate this, and no repairs have been reported (or are even evident) in the subject homes.

6.8 Opinion S-10

Dr. Russell Opinion S-10 *"The copper pipes at* [redacted] *were impacted by the corrosive water served during the Flint Water Crisis losing approximately 0.006 inches of the wall thickness of the pipe most likely during the period when orthophosphate was not added.* (4)

Dr. Russell's assertion that corrosion of the copper piping at [redacted] occurred during the Flint water event has no factual basis. The original thickness of the copper pipes are unknown, so we cannot calculate any loss in thickness. The measurement of a loss of 0.006-inches for Sample E could not be confirmed, and could be an error or a measurement taken from a bend in the pipe, which is naturally thinner. Visually, there is no evidence of corrosion.

6.9 Opinion S-11

Dr. Russell Opinion S-11 *"The lead levels remaining in the heavily corroded and tuberculated steel pipe sections collected from* [redacted] *(and most likely at all other similarly plumbed homes having water service laterals made from lead) are excessive and present a risk that can only be addressed by complete re-plumbing due to the severity of the corrosion damage, pitting of these pipes, and the high levels of lead remaining in the pipe scale. Due to their age, and as was demonstrated by the defense data collection with an XRF, the brass faucets and valves in these homes have high lead content which exceed the current standards for lead content by up to two orders of magnitude and likewise require removal and updating with fixtures that meet the current less than 0.25 percent lead requirement."* (4)

Dr. Russell claims that lead levels in the scale remaining in [redacted] piping (and elsewhere) are excessive and risky. The reported values of 41.8, 168 and 83.3 ppm are dry content, and should really be reported as mg/kg rather than ppm. They represent weight percentages of 0.00418, 0.0168, and 0.00833 weight percent, all of which are tiny percentages of the amount of lead that would have been present in the original galvanizing layer, as discussed above. Furthermore, the method of saw-cutting to cross-section the tubes (and expose the scale for sampling) could have introduced traces of lead from the exterior galvanizing layer on the pipes, and that could be what was measured.

The galvanized steel pipes at [redacted] are long past their expected life, and could be replaced to prevent failure and improve their reliability, but this has nothing to do with water quality during the 18 months of Flint River use in 2014 and 2015, just their advanced age.

7. REFERENCES

1. ATS preliminary results including photographs and XRF results, Nickolas Steinhoff, Dec. 9, 2022.
2. “Visual Inspection of Water Piping at [redacted], Flint MI 48503,” D.C. Crowe, Corrosion Probe, report to A. Ringstad, Campbell, Conroy and O’Neil, January 4, 2021.
3. “Visual Inspection of Water Piping at [redacted], Flint MI 48503,” D.C. Crowe, Corrosion Probe, report to A. Ringstad, Campbell, Conroy and O’Neil, January 4, 2021.
4. “Supplemental Report of Dr. Larry L. Russell”, *In Re* Flint Water Cases, No.16-cv-1044, October 18, 2022.
5. “Internal Corrosion of Water Distribution Systems,” second edition, AWWA Research Foundation and DVGW-Technologiezentrum Wasser, 1996, page 111.
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11. D.A. Lytle, M.R. Schock, J. Leo, and B. Barnes, “A Model for Estimating the Impact of Orthophosphate on Copper in Water,“ J.AWWA 110(10): E1-E-15 (2018).
12. Great Lakes Water Authority, “Corrosion Control and Water Testing,” June 2016.
13. Flint Water Data, published on-line by the City of Flint.

APPENDIX A – CURRICULUM VITAE OF DAVID C. CROWE

DAVID C. CROWE

(Retired) Registered Professional Engineer – Professional Engineers of Ontario

Member of the Association for Materials Protection and Performance (AMPP), formerly NACE

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GENERAL BACKGROUND

Materials and Corrosion Engineer with 35 years experience. Broad industrial and research experience, in the Pulp and Paper, Chemical Process, Power, and Water and Wastewater Treatment Industries. Projects have included equipment inspection and evaluation, failure analysis, materials selection, corrosion testing and monitoring. Excellent communication skills.

EDUCATION

Ph.D. Metallurgical Engineering, University of British Columbia, 1985
Thesis: The High Temperature Electrochemical Behavior of Carbon Steel in Alkaline Sulfide Solutions
M.A.Sc. Metallurgical Engineering, University of British Columbia, 1982
Thesis: Stress Corrosion Cracking of 316 Stainless Steel in Caustic Solutions
B.Sc. Mechanical Engineering, University of Manitoba, 1977

EXPERIENCE

2014-2023 PRINCIPAL CONSULTANT
2009-2014 SENIOR CONSULTANT
Corrosion Probe, Inc., Centerbrook, CT

- Materials and corrosion engineering and welding consultation for pulp and paper mills, water treatment and waste water treatment plants, chemical industry, refining, power plant scrubbers, waste incinerators, duplex stainless steel tank fabrication, fire sprinkler systems, HVAC, etc.

2006 - 2009 TECHNICAL DIRECTOR
David N. French Metallurgists, Brooks, KY

- Failure analysis of boiler tubes and other power plant equipment.
- Legal consultations

2006 DIRECTOR, Pulp & Paper Services
Acuren Inspection, LaPorte, TX

- Initiated offering of Engineering Services including corrosion and materials engineering consultation, inspection, shutdown support and failure analysis.
- Supported business development by sales calls to mills, research of target customers, conference participation and customer problem resolution.

1999-2005 STAFF ENGINEER
International Paper, Manufacturing Technology Center, Loveland, OH

1989-1999 SENIOR RESEARCH SCIENTIST, SENIOR APPLICATIONS ENGINEER
Union Camp Corporation Technology Center, Princeton, NJ

- Materials and corrosion consulting to pulp and paper mills and chemical plants with regard to recovery boilers, caustic area, digester, bleach plant, storage tanks, paper machines, control room electronics and other process equipment including effects of process changes and chemical cleaning.
- Improved safety and reliability of paper mills through equipment inspections, condition assessment and design of repairs. Established corporate inspection and repair standards for tanks and pressure vessels.
- Directed hundreds of metallurgical analyses to determine the root cause of failures, utilizing microstructural examination, electron microscopy, mechanical testing, etc.
- Performed lab and field corrosion studies, including development of new on-line corrosion monitoring methods for pulp and paper processes, resulting in better understanding of corrosion mechanisms.
- Reviewed capital and maintenance project proposals for materials selection.
- Participated in industry-wide research directed at corrosion problems in recovery boilers, digesters and paper machines.

1985-1989 ASSISTANT PROFESSOR and RESEARCH SCIENTIST
Institute of Paper Chemistry, Appleton, WI (now IPST at Georgia Tech)

- Materials and corrosion research relevant to pulp and paper mills.
- Taught 'Introduction to Materials Science' and 'Corrosion' courses. Seminars on 'Corrosion in the Pulp and Paper Industry.'

PROFESSIONAL AFFILIATIONS

- NACE International
  Past Chair T5H Committee - Corrosion in the Pulp and Paper Industry
  Past Chair T3T3 - On-Line Monitoring in the Pulp and Paper Industry

AWARDS

Walter Mueller Award, for best paper at the 7th International Symposium on Corrosion in the Pulp and Paper Industry.

Dennis M. Anliker Award, TAPPI Corrosion & Materials Engineering Committee, 2006.

CITIZENSHIP: United States of America, Canada

PUBLICATIONS: A list of publications is available on request.

APPENDIX B – FEE SCHEDULE FOR EXPERT WITNESS TESTIMONY

The billing rate for Dr. Crowe is $180.00/hr.

All travel and living costs will be invoiced at cost.

APPENDIX C – REFERENCES USED IN PREPARING THIS REPORT

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2. ASTM B88-03, "Standard Specification for Seamless Copper Water Tube," ASTM (2003).
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9. Expert Report of Dr. L. L. Russell, *In Re* Flint Water Cases, No.16-cv-1044, Jun. 30, 2020.
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